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FINAL REPORT

19980039

EFFECTS OF ROOT MAGGOTS ON CANOLA SEED YIELDS

Funded by
The Agriculture Development Fund

March 2002
Prepared by: Ag and Agri-Food Canada

SAF

Adding value to agriculture through research and development

Final Report

to the Saskatchewan Agricultural Development Fund

ADF Project #9800039

Effects of Root Maggots on Canola Seed Yields

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December, 2001

Abstract:

The object of this project was to assess canola response to feeding by crucifer root maggots. The study was designed to investigate the relationship between root maggot numbers and root injury levels, and the relationship between root injury and seed yield loss. This was accomplished by the introduction of known numbers of maggot adults or eggs into field cages containing Polish or Argentine canola. A quadrilinear response curve developed between maggot numbers and root injury levels, with root damage levels increasing with increasing levels of infestation; at high infestation levels, root damage ratings for both Polish and Argentine varieties levelled off. Sampling year had a strong effect on seed yield. AC Boreal Polish canola seed yields tended to increase above uninfested controls when feeding damage was light, but decreased with increased root injury. On the other hand, no consistent yield declines in AC Excel Argentine canola were seen at the levels of root damage found in the investigation.

Executive Summary:

Crucifer root maggots have been reported to cause up to 50% seed yield loss in Polish canola and 20% yield loss in Argentine canola in Alberta (Griffiths, 1991). Visual examination of canola root damage caused by root maggots has led to the development of a six point rating scale for damage severity (Dosdall et al. 1994). However, the relationship between degree of root injury and subsequent seed yield has not been determined. This project was carried out to investigate the relationship between root maggot injury levels and yield components of Polish and Argentine canola.

One laboratory and three field trials were undertaken at the AAFC Saskatoon Research Centre to address the issue. In all tests, different numbers of root maggots, in either egg or adult stage, were placed in proximity to plants of AC Boreal Polish canola or AC Excel Argentine canola. In the laboratory trial, individual plants were grown in pots and placed in screen cages; in field trials, seedlings were thinned to12 canola plants grown in mesh cages (Photograph 3). By varying the original infestation numbers, we hoped to vary root injury levels. At harvest, root injury, seed yield per cage and weight of 1000 seeds were measured. In some instances we also measured canola growth stage, root fresh and dry weights and crown diameter, and number of maggot larvae or pupae after an month of infestation or after harvest.

In one field trial, we attempted to vary moisture conditions in the cages by weekly additions of water to half the cages, but heavy rains resulted in little actual differences in "dry" and "moist" treatments. In the remaining field trials, we delayed infestation in half the cages to simulate early and late fly infestations. Also, in two trials we lifted the bases of a series of uninfested cages at the time of natural emergence of wild second generation root maggots in an attempt to discover any differences on canola growth between first and second generation infestation.

In all of the investigations, there was a strong relationship between maggot infestation level and root injury (Damage Index) sustained; the amount of damage found on roots of both canola species was directly and positively proportional to the level of original infestation. In most cases this was a quadri-linear relationship; that is, at low infestation levels damage increased linearly with the number of flies or eggs added to the plants, while at high infestation levels root damage levelled off. Also observed was the tenacity of larvae to feed on surrounding canola roots. In all four trials, there was at least some feeding on the uninfested controls, in some cases to a considerable degree. This is remarkable given the lengths to which we went in order to prevent immigration of larvae into control cages.

With the exception of harvest 2000, when the level of injury was greater in AC Boreal than in AC Excel roots, levels of injury to roots were generally similar in both Polish and Argentine canola. There were differences in canola species, however, in other variables measured. In the laboratory study, greater numbers of adult flies developed on AC Excel plants, which also fostered faster fly development than did AC Boreal. Also, seed yields were consistently higher in AC Excel than in AC Boreal cages. On the other hand, no consistent trend was seen in thousand seed weight; in one year AC Boreal had heavier seed, in the second year weight of 1000 seeds was similar between species, and in the third AC Excel seeds were heavier than those of AC Boreal.

Likewise, data from early and late infestations were not consistent between years. In 1999, greater numbers of larvae and greater levels of root injury were found in later infested cages, while in 2000 much more feeding damage was found in cages infested earlier. Previous studies (Dosdall et al.1994) found that late seeded canola late suffers less root maggot feeding injury than earlier seeded canola.

In the field studies, year had a strong effect on most variables measured. Root damage levels were similar in 1998 and 1999, but considerably higher in 2000. Conversely, seed yields were also heavier in 2000. It is likely that weather conditions had a greater effect on seed yields than did root maggot feeding.

When seed yields were compared to infestation and damage levels found in canola roots, cultivar differences again became apparent. In most cases, AC Boreal seed yields increased, then declined with increasing infestation levels and root damage. In 2000, seed yield decreased below those of control cages at damage index levels greater than 2.0. AC Excel seed yields, on the other hand, appeared to have no consistent relationship with maggot infestation levels, and often seemed to increase with the damage levels found in this study.

Root damage levels were lower and seed yields were higher in cages infested naturally with second generation flies than in cages infested at the time of the occurrence of first generation flies. The natural infestation levels may have been lower than our infestation of eggs, or canola plants at the end of July may be more able to withstand root pruning than canola infested earlier. A comparison of plants infested with 150 eggs at the end of June 1999 *versus* those infested at the end of July found decreased root injury of AC Boreal and similar root injury in AC Excel in the later infestation, with similar yields between infestation dates in both cultivars of canola.

Thousand seed weights in both canola were variable in this investigation, and did not appear to be related to root maggot injury to roots.

What are the implications of this research? While root maggot numbers definitely affect levels of root injury to both Polish and Argentine canola, at the levels of root injury found in this study, AC Excel seed yields do not appear to be affected by root maggot infestation. Under light feeding pressure, seed yields of both canolas appeared to increase somewhat. This may be the canola plant's response to stress, triggering increases to reproductive compared to vegetative growth. Further feeding tended to decrease AC Boreal seed yields but not those of AC Excel. It should be noted that the cages themselves influenced plant performance, decreasing effects of wind and temperature extremes. It may be that in an unprotected situation, Argentine plants are more stressed than those in our cages. Furthermore, the plants in this study were grown free of other sources of stress such as flea beetles, diamondback moth, or diseases; in 1999 and 2000, below normal seasonal temperatures would have favoured canola growth while hampering that of the maggots and any soil borne diseases present. It is likely that in conjunction with other factors, and especially in areas where canola root diseases are prevalent, root maggots will reduce seed yield in Argentine canola.

References:

Dosdall, L.M., Herbut, M., and Crowle, N.T. 1994. Susceptibilities of species and cultivars of canola and mustard to infestation by root maggots (*Delia* spp.) (Diptera: Anthomyiidae). *The Canadian Entomologist* 126: 251-260.

Griffiths, G.C.D. 1991. Economic assessment of cabbage maggot damage in canola. Farming for the Future technical Report FFF # 89-0444, Alberta Agriculture, Edmonton, AB.

Technical Report

1. Laboratory study: Canola AC Excel (*B. napus*) and AC Boreal (*B. rapa*) seeds were planted in 15 cm pots and placed in a growth cabinet maintained at a photoperiod of 16 hours light/ 8 hours dark, temperature of 21/15°C, and relative humidity approximately 55%. Seedlings were removed so that one plant remained in each pot. Root maggot eggs were obtained from the laboratory colony and were from newly laid to three days old in age at the time of placement in the cages.

Root maggot eggs were placed on moist filter paper at the rate of 0, 25, 50, 75 and 100 eggs per disk. Each disk had a notch removed so that the disks could be placed around the plant stem on top of the soil-less mix. The eggs were placed on AC Boreal at mid bud to early flower stage and on AC Excel at mid bud. The experiment was set up as a split plot experimental design with canola species as main plots and egg density as sub plots, with seven replicates.

Upon plant maturity the roots were rated as to maggot injury, using the 0 to 5 damage rating scale of Dosdall et al. (1994):

0 = no damage to roots
1 = slight feeding, <10% of tap root surface damaged
2 = 10 to 25% of root surface damaged
3 = 26 to 50% of root surface damaged, tunnelling into root interior
4 = 51 to 75% of root surface damaged, extensive tunnelling
5 = 76 to 100% of root damaged, or root severed by maggot feeding

To contain the flies that developed from the eggs, pots were placed in plastic bags with small air holes when the first flies started to appear; flies were then killed in the bags and counted daily to prevent re-infestation of roots by a subsequent generation of maggots.

Results:

a) Root Injury: Over all egg infestation levels, average ratings of root damage were similar between canola species, at 2.43 and 2.54 for AC Boreal and AC Excel, respectively.

One AC Excel control plant with no initial egg infestation showed slight maggot injury to its root; this may have been caused by a maggot emerging from an egg laid by a mated female fly escaping from an infested pot. Root damage ratings differed significantly with level of eggs placed near each root, increasing with increasing number of eggs per plant for both canola species ($P \leq 0.0001$)(Table1a and 1b). Root damage levelled off at the highest rate on plants of both species. This significant quadratic response ($P \leq 0.0001$ for both species)(Figure 1) means that greater root damage levels than seen here would be difficult to attain in this type of laboratory experiment.

b) Maggots: The number of pupae that developed on roots over infestation levels was not significantly different between AC Boreal and AC Excel. However, fly development was slower

and fewer adults were retrieved from AC Boreal than from AC Excel plants (Table 1a and b) ($P \leq 0001$). There was a significant linear relationship between egg infestation level and number of pupae and adult flies developing per pot ($P \leq 0.001$ for both canola species)(Table 1a and b). Thus, the number of pupae and adult flies retrieved at the end of the experiment was proportionate to the original number of eggs placed on the plants. No upper limit of fly survival was reached. A greater total number of pupae and adult flies (39.0 - 47.1% of the number of eggs placed per plant) developed on AC Excel than on AC Boreal (16.9 - 34.9%) ($P \leq 0.0003$). When the percentage of maggots that developed from eggs to pupae and adults was considered, there was a trend towards increased fly development with increased infestation level in AC Boreal plants ($P \leq 0.03$)(Table 1a); no such pattern occurred in AC Excel plants (Table 1b), which had about 40% survival and development at all infestation levels.

c) Seed Yield: At 4.99 g seed per plant, AC Excel outyielded AC Boreal plants, which averaged 2.55 g seed per plant ($P \leq 0.04$)(Table 1a and b). Despite increased root damage with increased egg infestation rates, over both cultivars seed yields were extremely variable within and among infestation levels ($P \leq 0.26$). However, contrasts found that differences in AC Boreal seed yields between the 50 and 100 egg per plant infestation rates were significant ($P \leq 0.05$)(Table 1a) Low levels of maggot infestation stimulated production of seed of AC Boreal, while higher levels reduced seed yield (quadratic relationship, $P \leq 0.05$)(Figure 2). There was no consistent relationship between maggot egg infestation rate and subsequent seed yield of AC Excel plants (Figure 2). When seed yield was plotted against root rating, the high within-treatment variability resulted in no significant relationship being found (Figure 3), although AC Boreal seed yield tended to decline with increased root damage. Similar to the lack of a relationship with egg infestation rate, AC Excel seed yield appeared unaffected by the root injury levels seen in this experiment.

Table 1a. Root damage rating on a scale of 0 to 5 caused by cabbage root maggots, number of root maggot pupae and adult flies, percentage of maggots developing to pupa or adult from initial egg infestation rates, and seed yield of plants of AC Boreal *Brassica rapa* canola infested with different levels of root maggot eggs in a growth chamber (n=7).

Infestation Rate (# eggs)	Root Rating	No. Pupae	No. Adult Flies	% Maggots Developing	Seed Yield (g/plant)
0	0[1] a	0 a	0 a	---	2.13 ab
25	1.71 b	2.7 b	1.6 a	17.1 a	2.67 ab
50	2.86 c	4.7 c	3.7 a	16.9 ab	4.38 a
75	3.86 d	14.3 d	5.4 a	26.3 ab	2.47 ab
100	3.71 cd	23.0 d	11.9 b	34.9 b	1.11 b

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 1b. Root damage rating on a scale of 0 to 5 caused by cabbage root maggots, number of root maggot pupae and adult flies, percentage of maggots developing to pupa or adult from initial egg infestation rates, and seed yield of plants of AC Excel *Brassica napus* canola infested with different levels of root maggot eggs in a growth chamber (n=7).

Infestation Rate (# eggs)	Root Rating	No. Pupae	No. Adult Flies	% Maggots Developing	Seed Yield (g/plant)
0	0.14[1] a	0 a	0 a	---	3.41 a
25	2.00 b	4.7 b	5.7 ab	41.7 a	5.37 a
50	3.14 c	11.4 c	10.1 b	43.1a	5.84 a
75	3.57 c	12.1 c	17.1 c	39.0 a	4.32 a
100	3.86 c	20.3 c	26.9 d	47.1 a	6.04 a

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

2. Field Investigations:

a) Preliminary Study Summer 1998

In the fall of 1997 cereal stubble plot land at the Saskatoon Research Centre farm was treated with the herbicide Edge® and fertilized to nutrient levels suitable for canola production. *B. rapa* cultivar AC Boreal and *B. napus* cultivar AC Excel were planted in 2 row, 3.0 m long plots, with four replicates per plot, in mid May 1998. Prior to seeding, seed was treated with Vitavax RS® flowable at a rate of 22.5 ml/kg seed for control of flea beetles and seedling diseases. Plants were seeded at a rate of 100 seeds per 3 m row, with single guard rows of Conquest barley seeded on either side of the canola rows. Twelve plants from the two canola rows per plot were caged in $1m^3$ D-shaped screen cages, and each cage was infested with one of four rates of root maggot adults (0, 20, 40, and 60 flies per cage) at early bud stage on June 26. Flies, in a 4:1 female:male ratio, approximating that of field collections at the time, were collected from sweeps of canola fields in the St. Brieux/Annnaheim areas or obtained from a laboratory colony of cabbage root maggot, *Delia radicum* L. All cages were watered with approximately 2.5 cm of water over the surface of the soil for 1 week after infestation to enhance survival of root maggot eggs and larvae; half of the cages continued to have water added to them for 4 weeks after the introduction of flies. Thus, the experimental design was a split-split plot, with main plots being moisture regime, sub-plots being canola cultivar, and sub-sub-plots being the fly infestation levels.

Two plants per cage were harvested in mid July and examined for root maggot damage. The remaining plants were harvested at maturity. Plants were rated for maggot injury to roots, 1000 seed weight, and seed yields per cage. Yield was correlated with adult infestation levels.

Results:

The weekly addition of water to half of the cages for four weeks after infestation had no direct impact on the subsequent amount of root injury, as measured either in July or at harvest, or on seed yield and 1000 seed weight ($P \geq 0.05$). Therefore, values for these variables were averaged over both moisture regimes.

a. Root injury:

Canola cultivar did not affect July root damage ratings, but initial fly infestation rates significantly affected amount of damage to the roots ($P \leq 0.0008$)(Table 2a). As expected, the greater the number of flies placed in the cages, the greater the amount of maggot damage. The only exception to this trend was damage to AC Boreal roots from the 40 fly infestation rate in July (Table 2b); for unknown reasons root injury was higher in this treatment than in the 60 fly treatment.

Root injury ratings at harvest increased significantly with initial fly infestation rate (Table 2 a,b,c, Figure 4). Unlike the results from potted plants in growth chambers, in which space may have been limiting, root damage did not appear to level off at the highest infestation rates. Root damage ratings were generally parallel between July measurement and harvest in September over all infestation rates except the uninfested control. Plants in control cages remained free of maggot

injury at the mid July rating, the time of pupation of the first generation of flies. However, at the end of the growing season all uninfested cages of both canola species had some level of maggot damage, and average root damage rates for the control treatment at harvest were relatively high (Table 2b,c). The screen on the cages was intact and impermeable to maggot flies. It is extremely unlikely that maggot pupae were in the soil at the time of canola seeding; therefore, root injury was most likely caused by larvae migrating from nearby, uncaged plants. Because no attempt was made to eliminate flies once they had emerged in the infested cages, a second generation of larvae resulted in increased injury to roots in these cages in August. A comparison of the injury levels in July and at harvest (Table 2a,b,c) indicates that, except for the control cages, the second generation of root maggot larvae did not contribute greatly to root injury levels at harvest.

b. Seed Yields:

While there was a trend for seed yields of AC Boreal plots to decrease with increasing fly densities above 20 per cage (Table 2b Figure 5a), AC Excel seed yield variation among infestation rates was very small. As a result, there were no significant differences between fly infestation rates and seed yield per cage for either cultivar (Table 2, Figure 5). The lack of an undamaged control may have contributed to this absence of maggot density effects. There were significant cultivar differences in both seed yield per cage and 1000 seed weight ($P \leq 0.001$ for both variables). AC Excel had a much greater seed yield per cage than AC Boreal in all fly treatments (74.4 *vs* 41.6 g seed/cage, respectively); conversely, the Argentine cultivar had a significantly lower thousand seed weight than AC Boreal seeds in all fly treatments, averaging 2.65 g/1000 seeds, as opposed to AC Boreal's 2.94 g/1000 seeds.

Although moisture regime had no direct effects on the variables measured, it did affect interactions. There was a significant moisture by infestation interaction in seed yield per cage ($P \leq 0.05$).Over light infestation levels of 20 flies per plant, seed yields increased under dry conditions. Likewise, there was a significant moisture by cultivar interaction in 1000 seed weight ($P \leq 0.05$)(Table 2d). Seed weight of AC Boreal plants increased with decreased moisture, while that of AC Excel remained relatively constant.

Table 2. Effects of moisture and root maggot flies on levels of root damage, seed yields, and 1000 seed weight of two cultivars of canola grown in field cages and infested with four densities of root maggot flies, Saskatoon, 1998.

a) combined over canola cultivars and moisture regimes

Fly Density / Cage	Damage Index - July	Damage Index - Harvest	Yield / Cage (g)	1000 Seed Weight (g)
0	0 a [1]	0.90 a	57.6 a	2.73 a
20	0.75 ab	1.28 ab	60.9 a	2.81 a
40	1.93 b	1.56 bc	57.6 a	2.83 a
60	1.80 b	1.90 c	55.9 a	2.83 a

b) *Brassica rapa* AC Boreal over moisture regimes

Fly Density / Cage	Damage Index - July	Damage Index - Harvest	Yield / Cage (g)	1000 Seed Weight (g)
0	0 a [1]	1.02 a	41.77 a	2.81 a
20	0.4 a	1.31 ab	46.17 a	2.93 a
40	2.58 b	1.76 ab	39.84 a	3.00 a
60	1.57 ab	2.00 b	38.7 a	3.04 a

c) *Brassica napus* AC Excel over moisture regimes

Fly Density / Cage	Damage Index - July	Damage Index - Harvest	Yield / Cage (g)	1000 Seed Weight (g)
0	0 a [1]	0.77 a	73.44 a	2.64 a
20	0.94 a	1.25 ab	75.67 a	2.68 a
40	1.43 a	1.36 ab	75.31 a	2.66 a
60	2.00 a	1.79 b	73.10 a	2.63 a

d) Thousand seed weight (g) over fly infestation levels

Moisture Regime	AC Boreal	AC Excel
Moist	2.87±0.07	2.69±0.04
Dry	3.02±0.07	2.61±0.05

[1] Root damage ratings within columns followed by the same letter are not significantly different, ANOVA at $P \leq 0.05$ and Tukey's studentized range test.

b) Field Trial 1999

The field experiment was repeated in 1999 with the following modifications. As in 1998, two moisture regimes, wet and dry, were planned; however, the numerous spring rains precluded the "dry" treatment. Instead, two infestation dates, approximately 10 days apart, were undertaken, to determine the effects of early and later infestation of root maggots on the canola. Plots were seeded on May 25, 1999 at the Saskatoon Research Centre farm. Rows were seeded at a rate of 100 seeds per 3 m row using a four row seeder. Rows 1 and 4 were barley, and rows 2 and 3 were *B. rapa*or *B.napus* canola. On June 8 and 9 one D-cage, 0.6 m^3 in volume, was placed over the middle two rows on each plot. Plants were counted prior to maggot introduction to ensure that each cage had 12 plants. From each cage, two plants were assessed for phenology. Just prior to maggot introduction, soil was watered.

Rather than introduction of adult flies to the cages, 0, 50, 100, and 150 eggs of *Delia radicum* L. collected from the laboratory colony were placed on moistened filter paper discs and set on the soil around each plant in the cages in four replicates. As well, a fifth treatment, cages that had no flies during the initial egg laying period of the natural population and the cage sides rolled up to allow entry by wild flies so as to monitor second generation damage, was also included. Thus the test was composed of 80 cages in a split-split plot design (2 infestation dates (main plots) x 2 canola species (sub-plots) x 5 infestation levels (sub-sub plots) x 4 replicates). Eggs for the first date (D1) were placed on plants on June 28 (replicates A and B) and June 29 (replicates C and D) and eggs for the second date (D2) were placed on plants on July 8 (replicates A, B, and C) and July 9 (replicate D). At the time of early infestation AC Boreal plants were in early bud, while those of AC Excel were bolting. D2 plants were in the early flowering stage when eggs were placed in the cages. A yellow sticky trap of 12x6 cm dimensions was placed in each cage and changed on a weekly basis to monitor fly emergence. In order to minimize immigration of maggots into the area under the cages, all canola plants from outside the cages of each plot were removed. One month after egg introduction, at approximately the end of the first fly generation, two roots per cage were sampled to determine the damage level done at this time. The plants were assessed for phenology, root rating, larval and pupal density, root length, root dry weight, and root diameter. Plant collections were made for the D1 treatment on July 28 (replicates A and B) and July 30 (replicates C and D) and D2 plants were collected on August 5. At this time flowering was almost complete and some pods had developing seeds..

At plant maturity a Hege combine was used to harvest plants. AC Boreal was harvested on September 17 and AC Excel was harvested on September 23. Seed samples were cleaned and yields and 1000 seed weights were measured. Roots were pulled from cages on the day of harvest and rated for damage on a scale of 0- no damage, to 5- complete severing of the root or more than 75% of the root eaten by maggots.

Data on infestation levels, root damage indices, timing of damage, soil moisture conditions and canola seed yields were assessed.

In a related investigation, we attempted to determine the effects of second generation root maggots on canola root healthy and seed yield. To this end two cages in each replicate of each canola species were not infested with eggs at the end of June; rather, at the end of July one cage in each replicate had 150 eggs placed at the base of each plant, while the other had the bottom screen of the cage lifted 30 cm so that second generation wild populations of root maggots could gain

access to the canola plants within. Plants were harvested and roots were rated for injury at the same time as the egg infestation trial.

Results:

i) Mid Season Root Analysis

At the end of July/beginning of August, near the end of the larval feeding period of the first generation of maggots, three of the variables that were monitored - infestation date, cultivars, and infestation rate - greatly affected the level of root injury by maggots. Over both cultivars and all egg infestation rates, root damage ratings for plants infested later were almost twice as great as those on plants infested early (2.22 and 1.17, respectively) (P= 0.012)(Table 3a). Root damage to AC Boreal plants (2.05) was significantly greater than to those of AC Excel (1.34)(P= 0.013). The increase in root injury to AC Boreal plants infested later in the season was greater than that to AC Excel plants (infestation date x cultivar interaction $P \leq 0.05$) (Table 3a). Root injury increased significantly with increased egg infestation (average for both canolas T0=0.00, T50=1.56, T100=2.32, T150=2.90) (P=0.0001). The quadratic response of ratings to egg density (Figure 6a) was significant for both canola cultivars (P=0.007), indicating that damage levelled off at higher egg infestation rates. This may have been due to a density dependent response, whereupon only a finite number of maggots could feed on canola roots without interference; above that number, larvae may have interacted with one another, starved or wandered away.

Plant growth characteristics, including growth stage, root length, dry weight, and crown diameter, had no clear correlation with the amount of root injury exhibited by roots sampled at this time.

Greater numbers of larvae were found in cages infested later in the season than earlier (4.77 *vs* 0.64, respectively)($P \leq 0.007$)(Table 3b). This greater number of maggots is probably the reason for the higher feeding damage levels found in the roots infested with eggs in July (Table 3a). However, the reason for the increased number of larvae in cages infested 10 days later than initially infested cages remains a mystery. An analysis of weather data during this period provides no unusual factors that may have resulted in decreased mortality of the second batch of eggs. The possibility of variability of fitness in the two batches of eggs, although produced from the laboratory colony of flies in a similar manner, cannot be discounted. Larval counts were not significantly different between cultivars; AC Boreal averaged 3.12 larvae per plant over all infestations, while AC Excel averaged 2.31 larvae per plant. However, differences between egg infestation levels were significant (Table 3b)(P=0.03). As expected, greater numbers of eggs resulted in greater numbers of larvae. Interestingly, unlike root damage, the number of larvae found did not appear to plateau with high egg infestation levels. Only nine *Delia* pupae were found in the entire trial at this time, six on AC Boreal roots and three on AC Excel roots. Roots in cages with the highest infestation rate, 150 eggs per plant, contained five of the nine pupae.

ii) Final Root Ratings

Root damage ratings for plants collected in September were not significantly different

between cultivars (AC Boreal=1.68, AC Excel=1.46) or infestation dates (June 28, 29 =1.41, July 8=1.73)(Table 3c). As with roots sampled earlier, damage ratings increased significantly with increased egg infestation levels (Table 3c)(P= 0.0001). Also as in the analysis of mid-season damage to roots, the quadratic response of late season root damage ratings to egg density was significant (P=0.0001), indicating a levelling off of damage at high infestation levels (Figure 6b).

Fall root ratings for the AC Boreal treatments infested July 8 were drastically lower than values observed on Boreal plants examined in mid-season (Tables 3a and 3c). The mid-season root damage ratings in this treatment were unusually high, and may have been skewed by the small sample size (n=2); later in the season Boreal plants may have outgrown to some extent the heavy mid season maggot injury.

iii) Seed Yields:

Seed yields expressed as grams of seed per cage were not significantly different between egg infestation dates (June 28,30 =43.5 g, July 8=45.4 g) or infestation levels (0=43.4, 50=48.6, 100=44.0, and 150=41.8 g, respectively)(Table 3d)(Figure 7).This suggests that root maggot damage ratings up to 2.70 do not result in significant yield declines for either AC Boreal or Excel. The highest maggot damage rating, 2.71 in the 150 egg per plant late infestation treatment of AC Boreal, resulted in a yield of 28.8 g, a seed yield similar to that found in the uninfested AC Boreal, which had no maggot damage and a yield of 27.3 g (Table 3d). In three of the four cultivar by infestation date combinations, the highest yields were found in cages with light maggot feeding pressure, that is, at infestation levels of 50 eggs per plant. Overall, AC Excel yield per cage (59.0 g) was greater than AC Boreal yields (29.9 g) (P=0.003), a yield difference typical of the two canola types.

A comparison of 1000 seed weights found no differences between dates or rates of egg infestation when combined over cultivars, but did find differences in 1000 seed weights between canola cultivars ($P \leq 0.01$), with AC Excel having, on average, heavier seed than AC Boreal (3.56 *vs* 3.28g, respectively) (Table 3e). AC Boreal plants that were grown in uninfested cages tended to have greater 1000 seed weights than seeds from plant grown in infested cages, while the reverse was true for AC Excel. Contrast analysis found this relationship to be significant for AC Boreal at the second infestation date (Table 3e)($P \leq 0.05$).

iv) Second Generation Fly Infestation

At the mid-season investigation of plants in cages in late July, none of the plants in the D1 treatments that were destined to but that had not yet been exposed to late infestation or wild flies had any evidence of root injury, maggots or pupae. At this time both canola species from the D2 treatments, yet to be infested with 150 eggs per plant, had very slight feeding damage, rated at 0.1. The root damage levels at harvest of plants in cages exposed to wild flies from July 28 (D1) onward was much lower than those in our cages infested with 50 eggs (Tables 3c, f), indicating that wild flies may not have found the open cages. Similarly, root damage index of AC Boreal plants infested with 150 eggs per plant late in July, 1.53 (Table 3f), was considerably lower than root damage from cages similarly infested at the end of June/beginning of July (ave. 3.21, Table

3a). Seed yields (47.5 g/cage) were much higher in the AC Boreal cages exposed to wild maggot flies than in infestation cages on June 28, July 8, or July 29 (Tables 3c, f). Thousand seed weights of AC Boreal seeds from cages exposed to second generation flies were between those of 0 and 50 eggs per plant in the cages infested earlier (Tables 3c, f). Root damage of AC Excel plants infested with wild flies was much lower than that of plants infested in late June, or early or late July (Tables 3a, f). However, AC Excel plants did not differ in seed yield, whether they were exposed to second generation flies or to early or late infestations of maggot eggs. Average thousand seed weights for AC Excel plants were lower in the cages exposed to the second generation of *Delia* flies than in cages that were infested with maggot eggs.

When high numbers of eggs were placed near caged, uninfested canola plants in late July, damage levels of AC Boreal roots at the end of the summer were lower than of roots infested with equal; numbers of eggs a month earlier (Table 3c and 3f). AC Excel roots infested with 150 eggs per plant late in July had about the same degree of injury as roots with high levels of eggs infested on either the first or second infestation date. Seed weights per cage were similar to those infested by eggs at the time of the first generation of flies for both canola species (Table 3d and f). Likewise, 1000 seed weights of plants of either cultivar infested with eggs in late July did not differ appreciably from 1000 seed weights of plants infested a month earlier (Table 3e and f).

Table 3a. Average mid-season ratings, on a scale of 0 (no damage) to 5 (root severed) of root damage caused by the cabbage root maggot on a scale of 0 to 5 as affected by date of maggot egg infestation, cultivar, and egg density per plant, 1999 (n=4).

		Root Damage Rating (0-5)				
		Infestation Rate (eggs per plant)				Mean Root
Infestation Date	Cultivar	0	50	100	150	Damage Rating
June 28	AC Boreal	0	1.29	2.00	2.29	1.4
	AC Excel	0	1	1.13	1.83	0.99
Mean		0	1.13	1.56	2.08	1.17 A[1]
July 8	AC Boreal	0.00	2.71	3.71	4.13	2.64
	AC Excel	0.00	1.20	2.63	3	1.71
Mean		0	2.08	3.13	3.56	2.22 B
Overall Mean		0.00 a	1.56 b	2.32 bc	2.90 c	1.69

[1] Mean root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 3b. Average number of cabbage root maggot larvae found on roots of two cultivars of canola infested with different numbers of eggs per plant on two different dates, 1999 (n=4). Larval numbers monitored one month after egg introduction.

		Number Larvae per Root				
		Infestation Rate (eggs per plant)				Mean Number
Infestation Date	Cultivar	0	50	100	150	Larvae/Root
June 28	AC Boreal	0	1.43	0.63	0.43	0.56
	AC Excel	0	0.13	0.13	3	0.78
Mean		0	0.73	0.38	1.62	0.64 A[1]
July 8	AC Boreal	0.00	2	5.86	11.6	5.69
	AC Excel	0.00	0.8	6.75	7.63	3.84
Mean		0	1.5	6.33	9.63	4.77 B
Overall Mean		0.00 a	1.07 b	3.26 b	6.03 c	2.6

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 3c. Average harvest ratings of root damage caused by the cabbage root maggot on a scale of 0 to 5 as affected by date of maggot egg infestation, canola cultivar, and egg infestation rate per plant, 1999 (n=4).

		Root Damage Rating (0-5)				
		Infestation Rate (eggs per plant)				Mean Root
Infestation Date	Cultivar	0	50	100	150	Damage Rating
June 28	AC Boreal	0.03 a	2.01 b	2.13 b	2.33 b	1.63
	AC Excel	0.00 a	1.33 b	1.55 b	1.93 b	1.2
Mean		0.01	1.67	1.84	2.13	1.41 A
July 8	AC Boreal	0.00 a	1.88 b	2.39 b	2.71 b	1.74
	AC Excel	0.03 a	1.83 b	2.50 b	2.53 b	1.72
Mean		0.01	1.86	2.45	2.62	1.73 B
Overall Mean		0.01 a	1.76 b	2.14 bc	2.37 c	1.57

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 3d. Average seed yield (g seed/cage) of two cultivars of canola grown in the field and infested with four levels of root maggots per plant on two separate dates, 1999 (n=4).

		Seed weight (g per cage)				
		Infestation Rate (eggs per plant)				Mean Seed
Infestation Date	Cultivar	0	50	100	150	Wt / Cage (g)
June 28	AC Boreal	31.6 a	36.2 a	34.2 a	32.3 a	33.6
	AC Excel	50.7 a	58.6 a	50.9 a	53.4 a	53.4
Mean		41.1	47.4	42.5	42.8	43.5 A
July 8	AC Boreal	26.4 a	24.4 a	24.1 a	28.8 a	25.9
	AC Excel	64.2 a	75.0 a	67.0 a	52.6 a	64.7
Mean		45.7	49.7	45.5	40.7	45.4A
Overall Mean		44.3 a	48.6 a	44.0 a	41.8 a	44.4

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 3e. Average thousand seed weight (g) of two cultivars of canola infested with four levels of root maggot eggs per plant on two separate dates, 1999 (n=4).

Infestation Date	Cultivar	1000 Seed Weight (g) Infestation Rate (eggs per plant) 0	50	100	150	Mean 1000 Seed Weight (g)
June 28	AC Boreal	3.56 a[1]	3.25 a	3.42 a	3.39 a	3.41
	AC Excel	3.36 a	3.53 a	3.44 a	3.54 a	3.47
Mean		3.46	3.39	3.43	3.48	3.44 A
July 8	AC Boreal	3.52 a	3.12 ab	2.92 b	3.12 ab	3.16
	AC Excel	3.48 a	3.53 a	3.68 a	3.96 a	3.66
Mean		3.48	3.32	3.3	3.54	3.41 A
Overall Mean		3.48 a	3.36 a	3.36 a	3.51 a	3.42

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 3f. Root damage index at harvest on a scale of 0, no damage, to 5, root completely severed, seed yield per cage, and thousand seed weight of two cultivars of canola that were exposed to wild populations of crucifer root maggots from July 28 until harvest or were infested with 150 eggs per plant on July 29, Saskatoon, 1999.

Canola Cultivar	2nd Generation Wild Fly Infestation Damage Index	Seed Yield/ Cage (g)	1000 Seed Weight (g)	150 Eggs per Plant at Time of 2nd Gen Damage Index	Seed Yield/ Cage (g)	1000 Seed Weight (g)
AC Boreal	0.45 a	47.5 a	3.28 a	1.53 a	30.9 a	3.11 a
AC Excel	0.53 a	64.0 b	3.16 a	2.40 b	57.7 b	3.40 a
Overall Mean	0.49	55.8	3.22	1.96	44.3	3.30

[1] Root damage ratings within columns are not significantly different, ANOVA and Tukey's studentized range test.

c. Field trial 2000

The field experiment in 2000 was a replicate of the one conducted in1999. The wet and dry moisture regimes of 1998 were discontinued in favour of two dates of placement of root maggot eggs near canola plants. As in 1999, the study was seeded in a Split-Split Plot design, with main plots being the two egg introduction dates, sub plots the cultivars, and sub-sub plots were larval densities. AC Excel and AC Boreal seeds were treated with Vitavax RS Flowable (22.5 ml/Kg seed) prior to seeding. On May 17, 2000, canola and barley rows were seeded with a four-row seeder at a rate of 100 seeds per 3 m row. Rows 1 and 4 were barley spacer rows, and rows 2 and 3 were the test canola. On May 31 one D-cage, 0.6 m^3 in volume, was placed over the middle two rows on each plot. In order to minimize secondary infestation of cages, all canola plants that were outside the cages were removed.

Plants were thinned prior to egg introduction to a density of 12 plants per cage. Just prior to egg introduction two randomly selected plants were assessed for phenology.

Eggs of cabbage root maggot, *Delia radicum* L., were collected from the laboratory colony and placed on filter paper disks at a rate of 0, 50, 75, and 100 eggs per plant (T0, T50, T75 and T100). The 1999 infestation rates of T0, T50, T100, and T150 eggs per plant could not be duplicated because of a shortage of viable root maggot eggs of the same age for all treatments at the time of infestation. Eggs were placed onto filter paper disks which in turn were placed in plastic petri dishes and transferred to the field cages. Disks were placed, one disk per plant, into cages on July 5 (D1) and 14 (D2). On July 5 plants were in the bolt to early flowering stage and on July 14 plants were in full flower. Sticky traps were placed into cages and were changed on a weekly basis to monitor fly emergence.

Four weeks post egg introduction, on August 2 and August 11 for D1 and D2, respectively, two plants were removed from each cage and assessed for phenology, root rating, larval and pupal density, root length, root dry weight, and root diameter. At this time flowering was almost complete and pods had developing seeds.

Harvesting procedures were similar to those in 1999. AC Boreal was harvested on September 17 and AC Excel was harvested on September 23, 2000. Seed samples were cleaned and yields and 1000 seed weights were measured. Roots were pulled from cages on the day of harvest and rated for damage.

A second study, to investigate the effects of naturally occurring field populations of second generation root maggots, was conducted in conjunction with the first trial. Along with the 0, 50, 75, and 100 eggs per plant treatments, one treatment had no eggs placed around plants initially, but the sides of the cages were lifted to a height of 30 cm at the end of July to stimulate egg-laying by first generation adult wild flies. Thus, root damage to these plants would have been from second generation flies only.

Results:

i) Agrometerological Conditions

The three-month period May to July, 2000, was dryer and cooler than long term normal

conditions (Table 5a). The observed mean temperature for May1-July 31 was cooler than the long-term normal value, while precipitation for this period was below normal. July, however, was wetter and warmer than normal, ideal conditions for root maggot development. In comparison, the spring of 1999 had normal temperatures with below normal precipitation, while July was wet and cool.

Suitable soil temperature and moisture are required for optimal hatch and establishment of *Delia radicum* populations, with warm/moist conditions being preferable to cool/dry conditions. Analysis of temperature and rainfall for the seven days post egg introduction showed that root damage ratings increased with increased rainfall and temperature (Table 5b).

ii) Mid-Season Root Analysis

At the beginning of August, at approximately the end of the larval feeding period of the first generation of maggots, the overall mean root damage rating was 1.49. At this time flowering was almost complete and some pods had green seeds. The average root damage index rating for plants infested July 14, 1.31, was similar to that found on plants infested July 5, which was 1.67 ($P=0.21$). Likewise, over both infestation dates and all infestation rates, average damage to AC Boreal roots (1.55) was similar to that found on AC Excel roots (1.41). Differences among treatments, however, were significant ($P \leq 0.0001$).Within and between canola cultivars, the average root damage value of uninfested plants, 0, was significantly lower than those of plants with 50, 75 or 100 maggot eggs placed around their crowns, the damage indices of which were 1.83, 2.22, and 2.22, respectively (Table 5a). As in 1999, the quadratic response was significant ($P \leq 0.0001$) for both cultivars, indicating that root damage increased with increased egg infestation rates only to a certain point, whereupon it levelled off and remained stable.

When inspected in early August, roots of plants infested on July 5 had more larvae associated with them than did roots infested later (D1= 0.67 larvae per root, D2= 0.30 larvae per root) ($P \leq 0.007$)(Table 5b). This effect was principally because of the influence of the highest infestation level. At 100 eggs per plant, numbers of maggots were significantly higher on roots of the earlier infestation than those that were infested July 14 (1.81 *vs* 0.25 larvae per root, respectively)(Table 5b)($P \leq 0.001$); date differences were not significant for other infestation levels. Numbers of maggot larvae on roots in early August were not significantly different between cultivars, with 0.40 and 0.55 larvae found per root of AC Boreal and AC Excel plants, respectively (Table 5b). Average differences in number of maggots between treatments over both cultivars and infestation dates were significant (Table 5b)($P=0.002$), with numbers on the uninfested control being significantly lower than larval numbers on the two highest infestation treatments (Table 5b).

iii) Final Root Damage Ratings and Yield

When roots were collected at harvest in September, the overall mean root damage index rating (D.I.) was 1.95. Despite our efforts at maintaining control cages root-maggot free, some feeding on control roots did occur, on AC Boreal roots more so than on AC Excel roots (Table 5c). The average damage rating for roots from cages infested on July 14 was significantly lower

than the average damage of those infested on July 5 (P=0.01) (Table 5c). Cultivar also significantly affected root injury (P= 0.005); the average root damage index rating for AC Boreal was 2.22, while that of AC Excel was 1.68. Root damage ratings were significantly different among egg infestation levels, with all infestations having significantly higher levels of root damage than the control, but with few differences in root damage among 50, 75, or 100 egg per plant infestation levels (Table 5c, Figure 8)(P=0.0001).

Canola seed yields, measured as g seed per cage, were not significantly different between infestation dates for data combined over cultivars (D1=60.6 g/cage, D2=66.4 g/cage), although AC Boreal seed yields were consistently lower in cages infested early than late (Table 5d). Seed yields were significantly different between cultivars (P=0.001); over both infestation dates, at 80.46 g per cage, AC Excel seed yield was greater than that of AC Boreal, which was 46.61 g per cage. Over both infestation dates and cultivars, seed yield varied significantly among egg infestation levels ($P \leq 0.01$)(Table 5d), with AC Boreal yields for all infestations being 21-25% less than that of uninfested cages (Figure 9). When seed yield was compared with root damage rating, a significant quadratic relationship was revealed (Figure 10). Root damage ratings above 2 decreased seed yield below that of the control. Conversely, seed yields from plants in the AC Excel cages did not vary statistically over infestation rates or root damage ratings (Table 5d, Figure 11).

Weight of 1000 seeds did not vary with infestation date or level (P=0.24 and 0.22, respectively). As in previous experiments, 1000 seed weight of AC Boreal was significantly less than that of AC Excel (3.24 and 3.76 g, respectively)($P \leq 0.004$)(Table 5e).

iv) Natural Infestation of Second Generation Wild Flies

Root damage ratings for plants in cages exposed to wild fly populations ranged between 0.63-2.06; within each cultivar, damage from this naturally occurring second generation was below that of any of the treatments infested with maggot eggs (Tables 5c, 5f). Average damage to AC Boreal roots, 1.96, was higher than that to AC Excel roots, 0.80 (P=0.02). It is difficult to assess whether the cultivar differences in feeding injury levels are due to preference for AC Boreal or if AC Boreal is more susceptible to maggot damage. Seed yields were greater from AC Excel plants than from AC Boreal plants (Table 5f) (P=0.01). The seed yields of AC Boreal plants infested with wild second generation flies was much higher than seed yields of Boreal infested with eggs at the time of the first generation (Tables 5d, f). On the other hand, AC Excel seed yields from second generation fly cages was comparable to those of yields from plants infested in July. For both cultivars, thousand seed weights of plants in second generation fly infested cages were lower than those in cages infested both July 5 and 14 (Tables 5e, f), but only the differences among treatments on July 5 were significant ($0.0001 \leq P \leq 0.005$). The reasons for this sharp decrease in seed weight are uncertain.

Table 4a. May-July temperature and precipitation at the site of a trial investigating the effects of root maggots on canola at Saskatoon for 1999 and 2000, and 30-year normal values.

Month	Rain (mm)			Mean Temperature (°C)		
	1999	2000	Normal	1999	2000	Normal
May	40.5	13.0	41.6	11.1	10.2	11.6
June	60.0	45.0	63.6	15.1	14.2	15.9
July	96.5	74.0	55.7	16.4	19.1	18.3
Total	197.0	132.0	169.0	14.2	14.5	15.3

Table 4b. Comparison of mid-season canola root damage index (D.I.) ratings, on a scale of 0 to 5, with total rainfall and mean temperatures in the 7 day period after earlier (D1) and later (D2) egg introduction to cages, Saskatoon, 1999 - 2000.

Variable	1999- D1	1999- D2	2000- D1	2000- D2
Rain (mm)	7	28	27.0	13.0
Temp. (°C)	14.9	18.2	18.2	16.4
Root D.I.	1.17	2.2	1.65	1.31

Table 5a. Mid-season root damage ratings, on a scale of 0 to 5, of two canola cultivars grown in cages in the field and infested at different dates with differing levels of root maggot eggs per plant, Saskatoon, 2000.

		Root Damage Rating (0-5) Infestation rate (eggs per plant)				Mean Root Damage Rating
Date Infested	Cultivar	0	50	75	100	Index
July 5	AC Boreal	0 a[1]	1.50 b	2.50 c	2.63 c	1.66
	AC Excel	0	1.50 b	2.50 c	2.75 c	1.69
Mean damage		0	1.50	2.50	2.69	1.67 A
July 14	AC Boreal	0	1.75 b	1.88 b	2.13 b	1.44
	AC Excel	0	1.38 b	2.00 b	1.38 b	1.19
Mean damage		0	1.56	1.94	1.75	1.31 A
Overall mean		0 a	1.53 b	2.22 c	2.22 c	1.49

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 5b. Larval densities found at mid-season on roots of two canola cultivars grown in field cages and infested at different dates with no, 50, 75, or 100 root maggot eggs per plant, Saskatoon, 2000.

		Number Larvae per Root Infestation rate (eggs per plant)				Mean Number
Date Infested	Cultivar	0	50	75	100	Larvae per Root
July 5	AC Boreal	0 a[1]	0.63 ab	0.38 ab	1.50 b	0.63
	AC Excel	0	0.13 ab	0.63 ab	2.13 c	0.72
Mean no. larvae		0	0.38	0.50	1.81	0.67 A
July 14	AC Boreal	0.13 a	0.13 a	0	0.38 a	0.16
	AC Excel	0	0.38 ab	1.25 b	0.13 a	0.44
Mean no. larvae		0.06	0.25	0.63	0.25	0.30 B
Overall mean		0.03 a	0.31 ab	0.56 bc	1.03 c	0.48

[1] Number of larvae per root over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 5c. Damage index ratings (D.I.) on a scale from 0, no damage, to 5, root severed, of roots of two canola cultivars at harvest when infested on two infestation dates by four different levels of root maggot eggs per plant, Saskatoon, 2000.

		Root Damage Rating (0-5)				
		Infestation Rate (eggs per plant)				Mean Root
Date Infested	Cultivar	0	50	75	100	Damage Rating
July 5	AC Boreal	0.38 a [1]	3.02 b	3.18 b	3.40 b	2.49
	AC Excel	0.05 a	2.36 b	2.98 b	3.05 b	2.11 A
Mean D.I.		0.22	2.68	3.08	3.23	2.3
July 14	AC Boreal	0.43 a	2.21 b	2.53 b	2.64 b	1.95
	AC Excel	0.05 a	1.45 bc	1.93 c	1.63 bc	1.26
Mean D.I.		0.24	1.83	2.23	2.13	1.61 B
Overall Mean		0.23 a	2.26 b	2.65 b	2.68 b	1.95

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 5d. Seed yields per cage (g) of two cultivars of canola when infested on one of two infestation dates by four different levels of root maggot eggs per plant, Saskatoon, 2000.

		Seed Weight (g/cage)				
		Infestation Rate (eggs per plant)				Mean Seed
Date Infested	Cultivar	0	50	75	100	Weight (g/cage)
July 5	AC Boreal	49.1 a [1]	32.9 b	41.0 ab	33.2 ab	39
	AC Excel	77.4 a	72.5 a	89.3 a	89.8 a	82.2
Mean D1		63.2	52.7	65.2	61.4	60.6 A[1]
July 14	AC Boreal	63.6 a	54.2 a	47.8 a	51.2 a	54.2
	AC Excel	78.2 a	79.3 a	80.1 a	77.2 a	78.7
Mean D2		70.9	66.7	63.9	64.2	66.4 A
Overall Mean		67.1 a	59.7 b	64.5 ab	62.8 ab	63.5

[1] Seed yields over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 5e. Average thousand seed weight (g) of two cultivars of canola infested with four levels of root maggot eggs per plant on two separate dates, 2000 (n=4).

		1000 Seed Weight (g)				
		Egg Infestation Rate				Mean 1000
Date Infested	Cultivar	0	50	75	100	Seed Weight (g)
July 5	AC Boreal	3.50 a[1]	3.32 a	3.17 a	3.08 a	3.27
	AC Excel	3.67 a	3.75 a	3.92 a	3.92 a	3.82
Mean		3.58	3.54	3.55	3.5	3.54 A
July 14	AC Boreal	3.32 a	3.00 a	3.42 a	3.41 a	3.27
	AC Excel	4.00 a	3.67 ab	3.50 b	3.67 ab	3.71
Mean		3.62	3.32	3.46	3.54	3.49 A
Overall Mean		3.62 a	3.44 a	3.50 a	3.538 a	3.52

[1] Root damage ratings over dates and infestation levels followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Table 5f. Root damage index ratings at harvest on a scale from 0, no damage, to 5, root completely eaten, of roots of two cultivars of canola and seed yields per cage when exposed to wild-type field populations of crucifer root maggots in late July, Saskatoon, 2000.

	Damage Rating	Seed yield	1000 Seed Weight
AC Boreal	1.96 a[1]	66.0 b	2.79 b
AC Excel	0.80 b	87.6 a	3.16 a
Mean	1.38	76.8	2.98

[1] Root damage ratings in columns between cultivars followed by the same letter are not significantly different, ANOVA and Tukey's studentized range test.

Figure 1. Relationship between initial root maggot egg infestation rate per canola plant and resulting level of root injury, on a scale of 0, undamaged, to 5, root completely severed, of two cultivars of canola grown in a growth chamber.

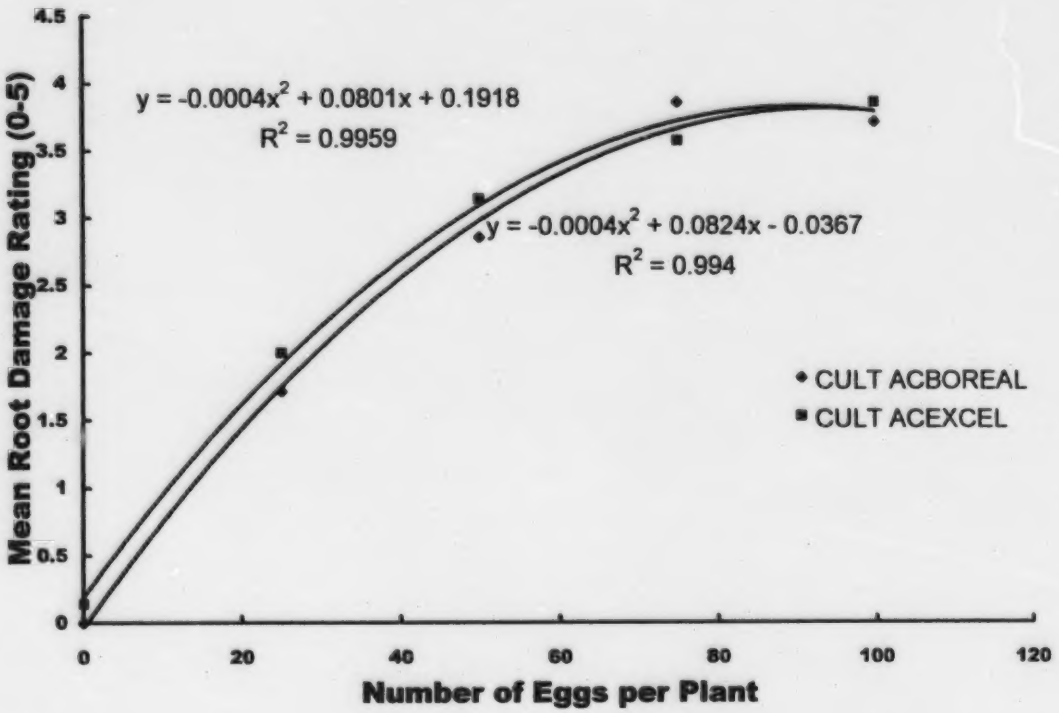


Figure 2. Relationship between initial egg infestation level of cabbage root maggot, *Delia radicum*, and seed yield of AC Boreal *Brassica rapa* and AC Excel *B. napus* canola plants grown singly in pots in a growth chamber.

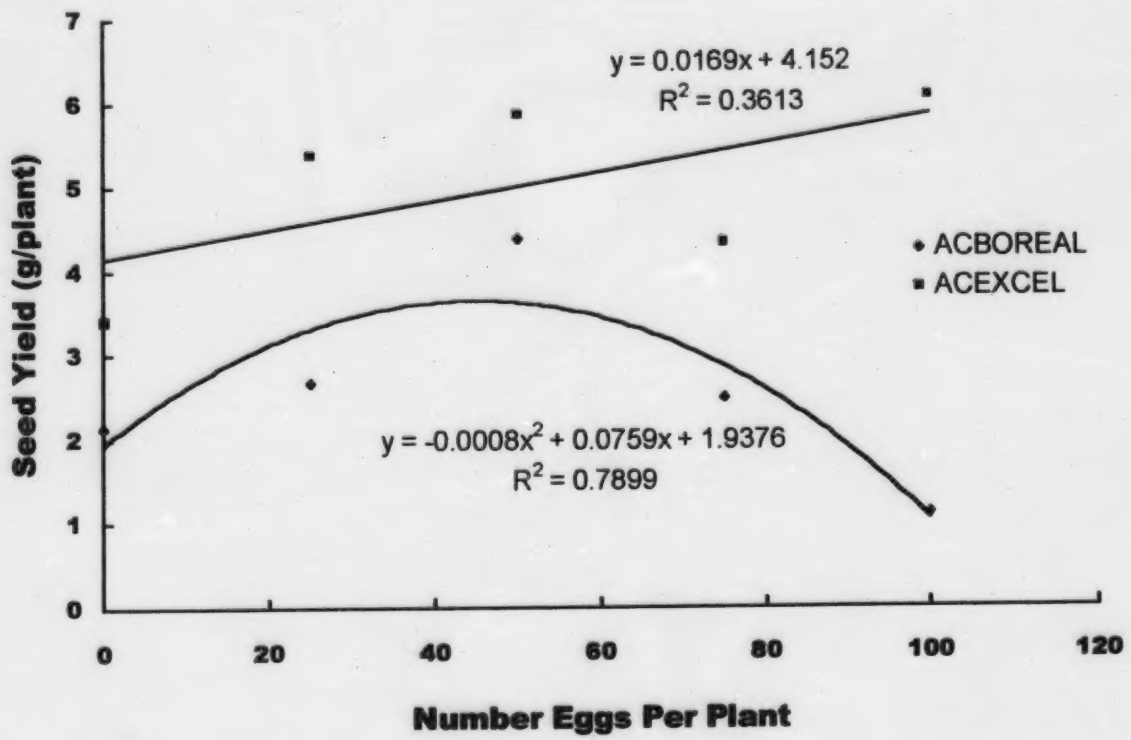


Figure 3. Relationship between level of root damage on a scale of 0, undamaged, to 5, root completely severed, caused by cabbage root maggot, *Delia radicum*, and seed yield of AC Boreal *Brassica rapa* and AC Excel *B. napus* canola grown in a growth chamber.

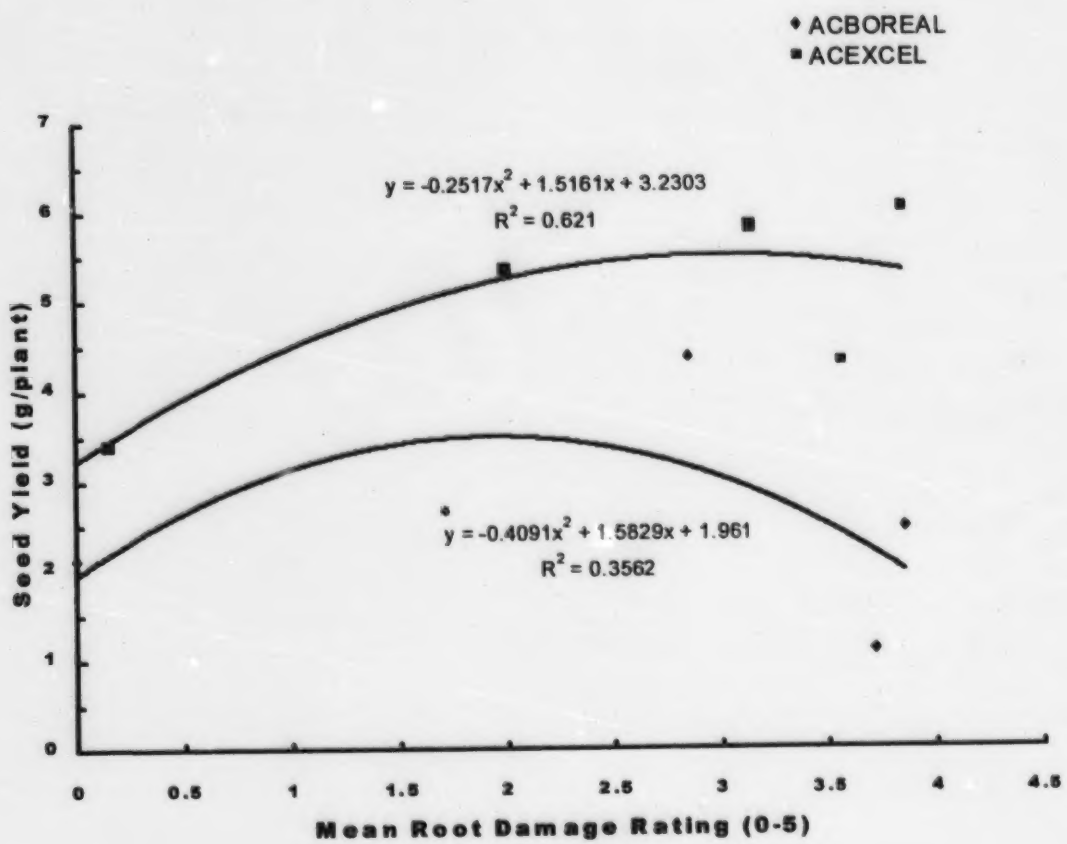


Figure 4. Relationship between initial root maggot fly infestation rate per cage and resulting level of root injury on a scale of 0, undamaged, to 5, root completely severed, of two cultivars of canola grown in the field near Saskatoon in 1998.

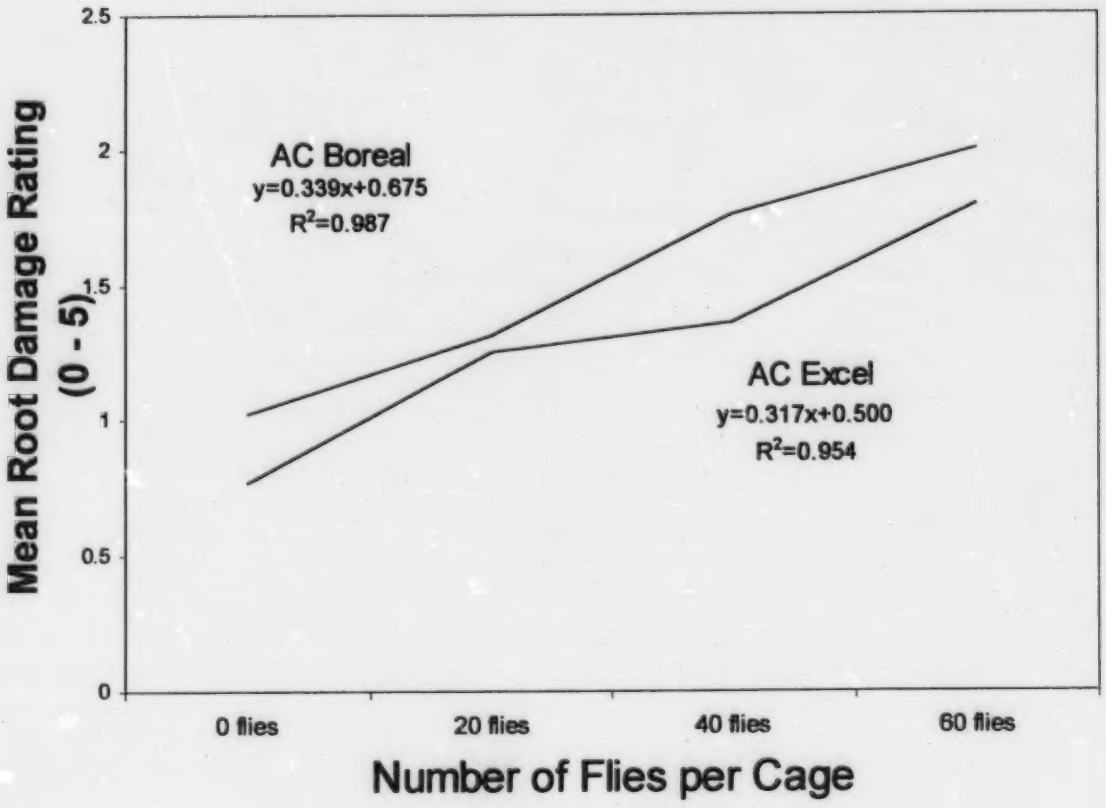


Figure 5 a. Relationship between initial fly infestation rate and seed yield per cage of AC Excel *Brassica napus* plants grown in the field near Saskatoon, 1998.

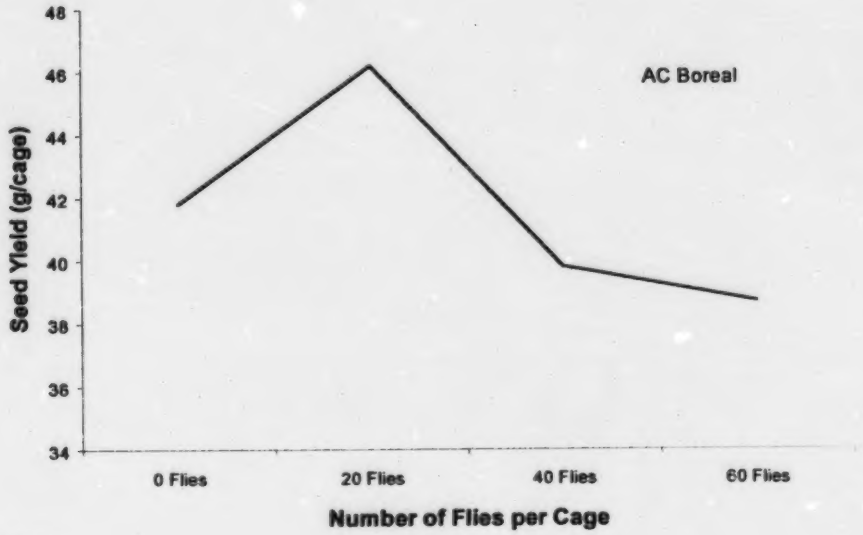


Figure 5b. Relationship between initial fly infestation rate and seed yield per cage of AC Boreal *Brassica rapa* plants grown in the field near Saskatoon, 1998.

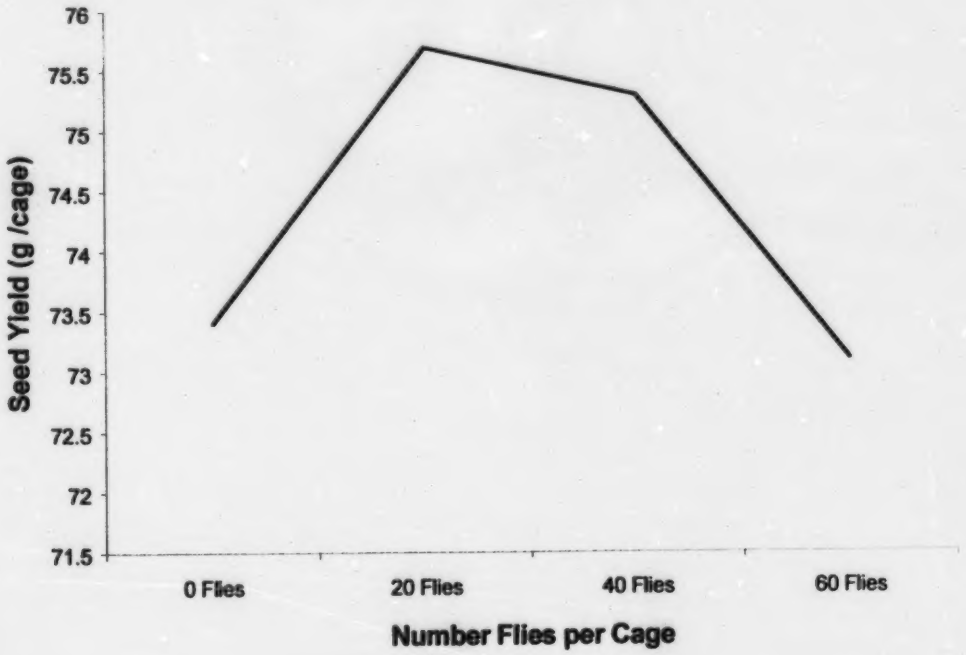


Figure 6a. Relationship between initial root maggot egg densities (number per plant) and mid season canola root damage ratings of canola plants grown in field cages near Saskatoon, 1999. Each data point represents mean values over two egg infestation dates (June 28,30 and July 8) and two cultivars (AC Excel and AC Boreal) (n=16).

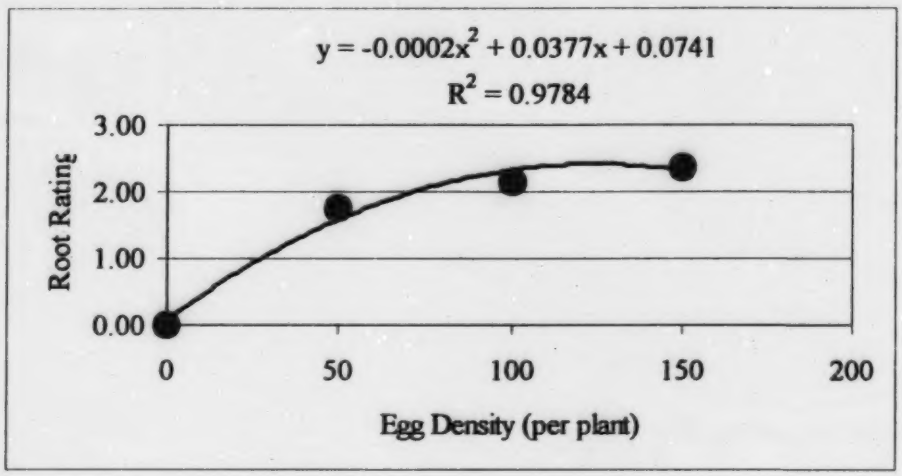


Figure 6b. Relationship between initial egg densities (number per plant) and harvest root damage ratings of canola plants grown in field cages near Saskatoon, 1999. Each data point represents mean values across two egg infestation dates (June 28/30 and July 8) and two cultivars (AC Excel and AC Boreal) (n=16).

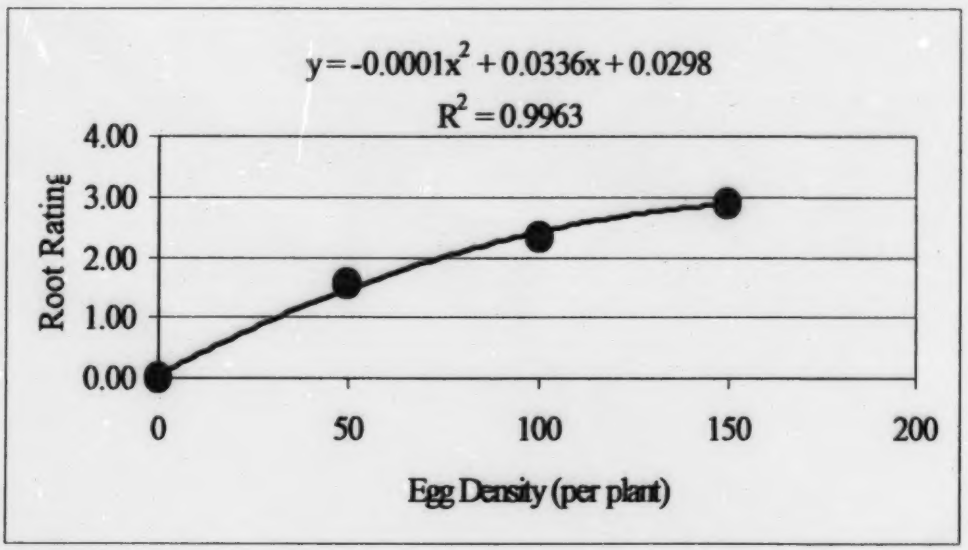


Figure 7. Relationship between densities of root maggot eggs and seed yields per cage of two cultivars of canola grown in field cages near Saskatoon, 1999 (n=4).

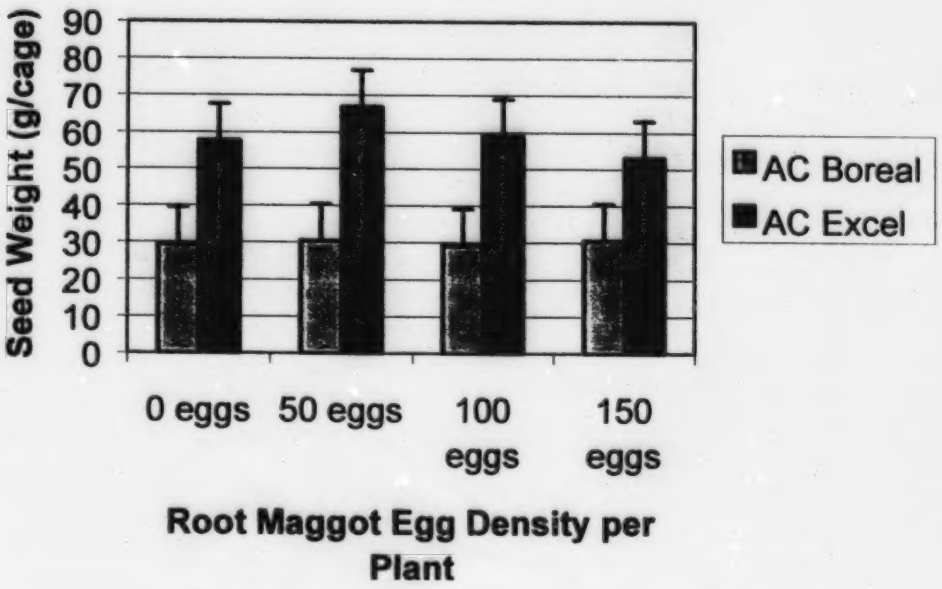


Figure 8. Relationship between initial root maggot egg densities (number per plant) and canola harvest root damage ratings, 2000. Each data point represents mean values over two egg infestation dates.

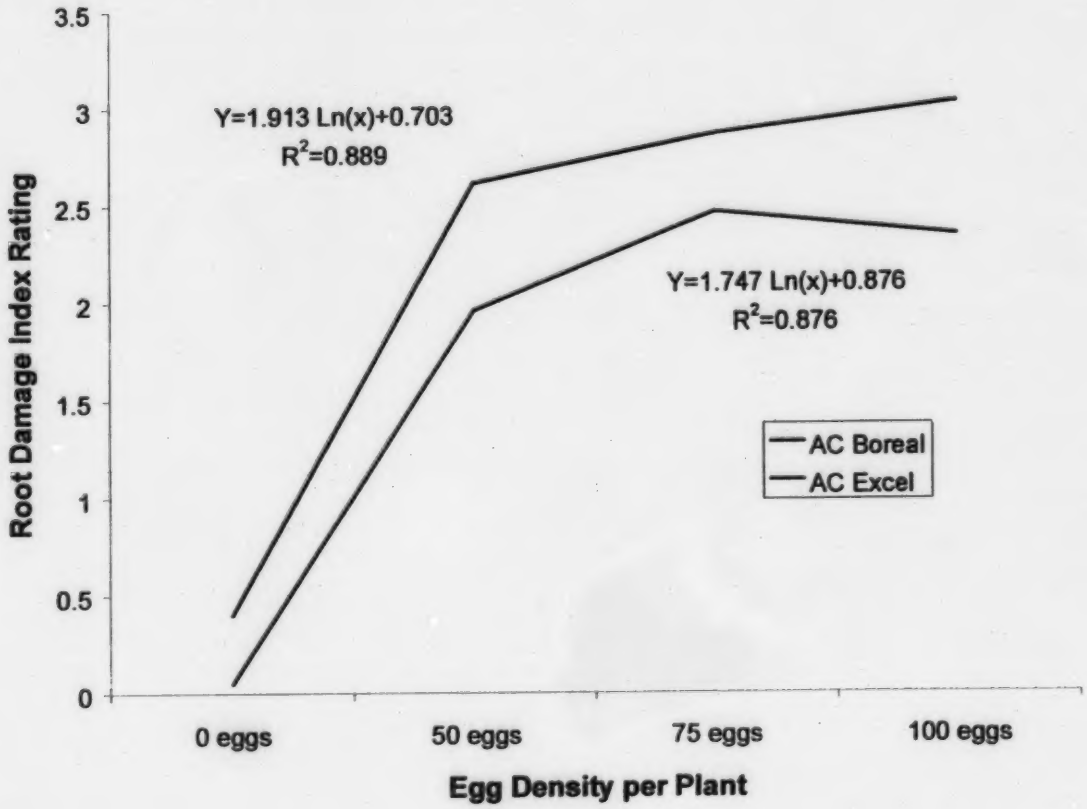


Figure 9. Seed yield, expressed as a percent of seed from uninfested cages (T0), for plants of AC Boreal and AC Excel canola caged with three different levels of root maggot eggs on two dates, Saskatoon, 2000.

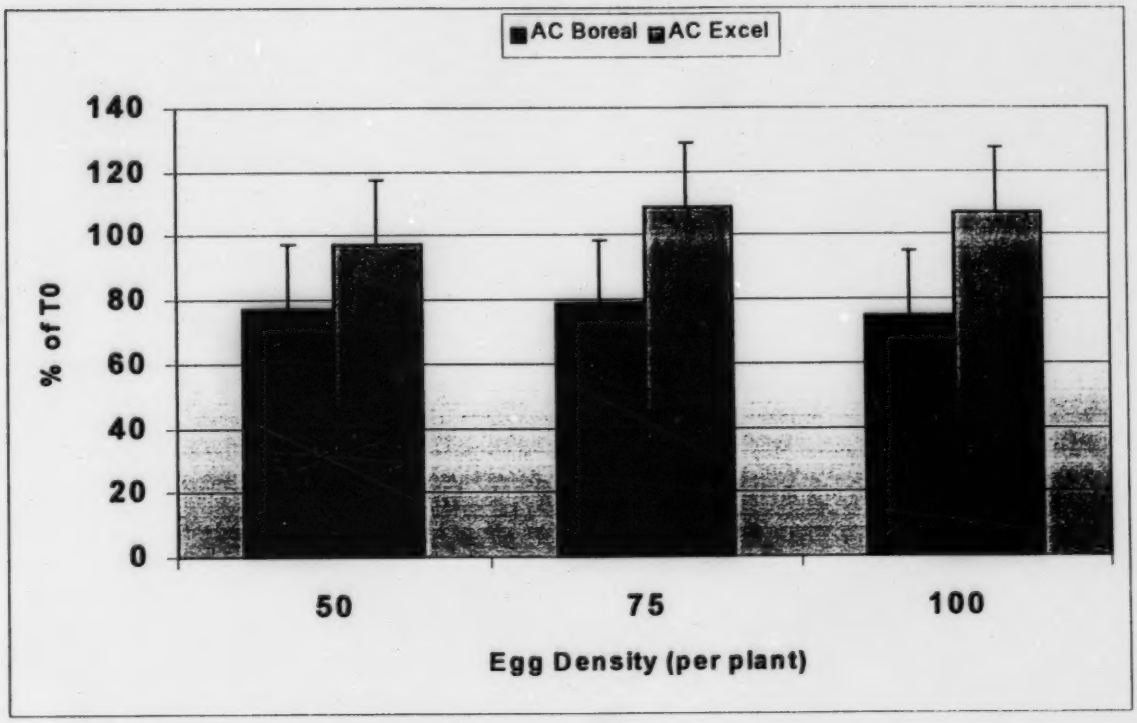


Figure 10. Relationship between seed yield per cage of AC Boreal canola and mean level of damage to canola roots on a 0 to 5 scale in a field cage experiment at Saskatoon, 1999 and 2000.

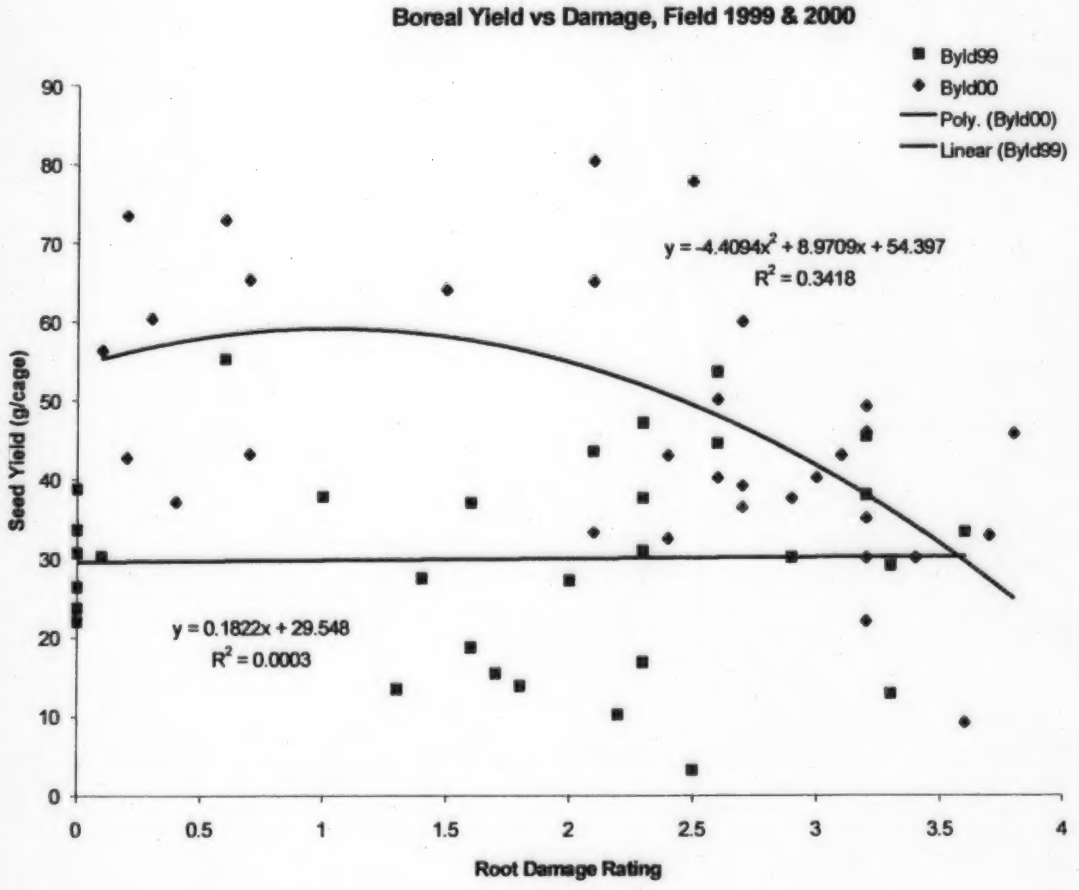
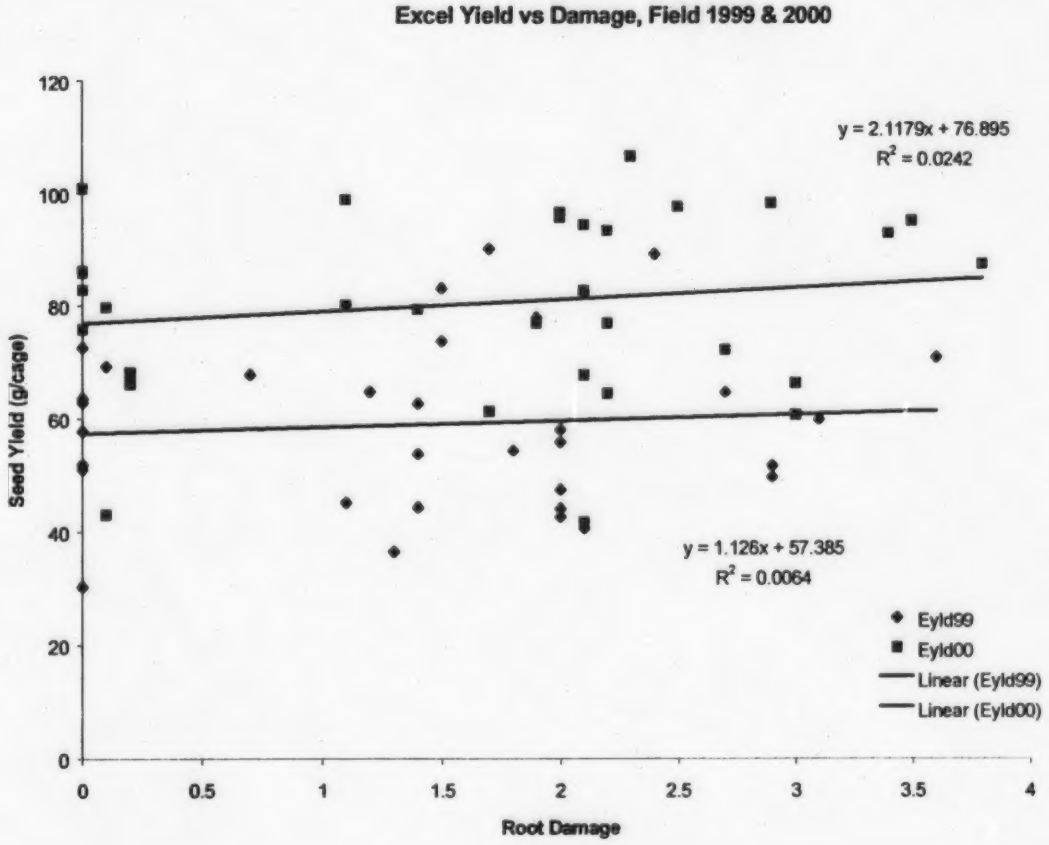


Figure 11. Relationship between seed yield per cage of AC Excel canola and mean level of damage to canola roots on a 0 to 5 scale in a field cage experiment at Saskatoon, 1999 and 2000.



No equipment was purchased in the conduct of this grant.

Project Development Materials:

Data from this project was discussed and the funding sponsorship of ADF was acknowledged at the following presentations:

a) Soroka J. 1999. Oilseed Entomology Update. Root Maggots - Biology and Severity. presentation to researchers at Saskatoon Research Centre, January 18, 1999.

b) Soroka J. 1999. Breeding Canola Resistant to Root Maggots. Invited talk given to Western Committee on Crop Pests annual meeting, Penticton, B.C. October 17, 1999.

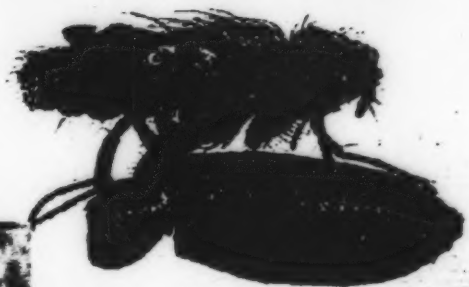
c) Soroka, J.J., R.H. Elliott, G. Rakow, K.C. Falk, and L.M. Dosdall. 2000. Resistance of Insects to Root Maggot Complex *Delia* spp. (Diptera: Anthomyiidae). Poster presentation at the International Plant Resistance to Insects Workshop, Fort Collins, Colorado, Feb. 28 - Mar. 2, 2000.

d) Soroka, J.J. 2000. Forage and Canola Insect Pests. Invited talk to delegates of the B.C. Grain Growers' Tour of the Peace River District, Rolla, B.C., July 27, 2000.

The results of the project are intended for a scientific publication entitled "The Effects of Root Maggot Infestation Levels on Root Injury to and Seed Yields of Oilseed Rape (*Brassica rapa* and *B. napus)*" by J.J. Soroka, O.O. Olfert, and R. Weiss.

Project Photos: **A)** **B)**

C)



D)

Photos A - D: Life cycle of cabbage root maggot, *Delia radicum* L.

A) eggs laid at the crown of a mustard plant

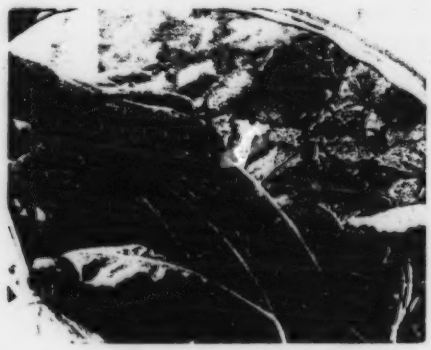
B) maggot feeding on a canola root

C) adult fly newly emerged from pupal case

D) female root maggot laying eggs on plant in growth chamber study

E) Experimental set up of field trial to assess the relationship between root injury caused by crucifer root maggots and canola seed yield, Saskatoon, 1999 - 2000.

F. View inside field cage just prior to placement of root maggot eggs.



G) Interior view of field cage, showing filter paper collars surrounding each plant, upon which were placed one of four densities of root maggot eggs.

H) Canola root heavily damaged by root maggots. Maggot tunnels serve as entry point for soil diseases, increasing root injury.

Acknowledgements

The researchers would like to acknowledge the techical assistance of Larry Grenkow, Bryan Sarauer, Jennifer Lazorko, Chris MacQuarry, and Christine Willison for their help with this project, as well as that of the numerous summer student who assisted us. The administrative patience of Bruce Baumann is appreciated.